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Linking scenarios across geographical scales in international environmental assessments

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Abstract

The development and analysis of scenarios or plausible futures has evolved to be a useful approach for dealing with uncertainty about future developments in a structured and integrated manner. Commonly, scenario exercises have focussed on processes at one specific geographic scale. Recently scenario-based approaches have also been used to address multi-scale processes or to link scenarios developed at various geographical scales with each other in order to better understand the interaction of processes across scales.

The level of interconnectedness across scales will vary, and depends largely on the approaches used to develop multi-scale scenarios. We distinguish five levels of interconnectedness scenarios may display across scales: (a) Equivalent, (b) Consistent, (c) Coherent, (d) Comparable, and (e) Complementary. Furthermore, we describe five different types of coupled scenario development processes: (a) Joint, (b) Parallel, (c) Iterative, (d) Consecutive, and (e) Independent.

Based on this nomenclature, the relationship between the level of interconnectedness of scenarios and the degree of coupling of scenario development processes across geographical scales is discussed. Which process is best suited and how much interconnectedness is needed, will depend both on the focal issue and the primary purpose of the scenario exercise, i.e. whether the aim is education, scientific exploration, or decision-support.
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Keywords: Scenarios; Assessments; Scale; Uncertainty; Complexity; Environment; Future; Multi-scale

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1. Introduction

Over the past decades, scientists and policymakers alike have become increasingly aware of the complex and manifold linkages between ecological and human systems, and have looked for new ways of understanding and responding to changes in both systems and their interactions. To this effect, several recent international environmental assessments have aimed to inform societal response to the looming global environmental changes and their impacts and to help support sustainable development (see, for example, [1–3]).

The notion of sustainable development builds on the very need to think about the long-term consequences of actions taken today — i.e. *"to seek to meet the needs of the present without compromising the ability of future generations to meet their own needs, in economic, social and environmental terms"* [4]. Many economic, social and environmental processes unfold over long time spans, and this often requires that comprehensive assessments look ahead over 50 years or more when seeking new insights on how decisions taken today may affect our future. The inertia of the climate system, for example, is well known and has made decision-makers around the world aware of how difficult it might be to reverse past actions.

In addition, the concept of sustainable development requires integrated approaches to assess different plausible pathways into the future. Recognising the complexity of the socio-ecological system, one can only begin to understand its dynamics by addressing the interactions and feedbacks between issues (e.g. economic, social and environmental consequences). Furthermore, many interactions and feedbacks play out over time (or temporal scale, i.e. in past, present and future contexts) and space (or geographical scale, i.e. at local, regional and global scale) — these are referred to as 'cross-scale' or 'multi-scale' processes. To take account of this array of complexity in the context of decision-making, a number of research-supported approaches have been developed and advanced.

The development and analysis of scenarios or plausible futures has evolved to be a useful approach to dealing with uncertainties about future development (see Section 2 for a fuller account of scenario analysis). In essence, it is the very nature of scenario exercises to integrate across a range of issues and their interactions, and to think through causal relationships over time. A growing body of research has demonstrated how scenario development can be used to better understand current and future interactions of various factors or driving forces (examples include [5–8]).

Processes at different geographical scales, however, commonly unfold over different time scales: The more aggregated the geographical scale (e.g. the global scale), the slower a system's dynamics unfold. Conversely, at a less aggregated geographical scale (e.g. the local scale) the socio-ecological dynamics are more responsive. Thus, in a hierarchical system, the more aggregated level can be seen to set the boundary conditions for any lower level of aggregation. Commonly, scenario exercises focus on processes at a specific geographic scale (i.e. so as to clearly distinguish uncertainties at one scale from those at another). Nevertheless, scenario-based approaches have recently also been used to address multi-scale processes or to link scenarios developed at various geographical scales with each other to understand more fully the cross-scale interactions [3,9].

With this paper, we hope to contribute to the on-going discussion on scenario development approaches by providing a description of concepts to link scenarios across different geographical scales. We give a more detailed description of the scenario approach in general and its applications. Then we systematically describe different concepts of how scenario development processes can be coupled (or not) across geographical scales, and how scenarios themselves may be linked (or not). Where possible we provide examples from recent scenario exercises to illustrate each concept and discuss benefits and constraints. Finally, we conclude with a reflection on the usefulness of linking scenarios across geographical scales in view of supporting international environmental assessments.

2. Developing scenarios in international environmental assessments

The development and analysis of scenarios provides an approach to thinking through plausible future developments and related uncertainties in a structured, yet creative manner. Scenario-based approaches have a long tradition in the realms of military, economics, and management (e.g. [7,8,10,11]), and have more recently also received much prominence within international environmental assessments (e.g. [1–3,12] — see below for more detail and further examples).

While no definitive definition exists, scenarios have been described as “plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships” [3] or “plausible descriptions of how the future may unfold based on ‘if–then’ propositions” [13]. Scenarios present, simply put, stories about the future, which can be told either qualitatively (in words or pictures), quantitatively (as numerical estimates) or by combining both. They are usually best used by making comparisons across a set of different scenarios [14].

Both qualitative and quantitative scenarios can be developed using either participatory approaches (for example, policy exercises (e.g. [15]) and other stakeholder processes (e.g. [16])), or analytical approaches (for example, mathematical modelling (e.g. [17]), or by combining both [18]. Indeed, recent international environmental assessments have commonly attempted combining different approaches to produce sets of qualitative narratives backed-up by quantitative modelling [12,18].

Scenario-based approaches are particularly useful when addressing the considerable uncertainty about future trajectories in complex systems — see Fig. 1. Here, uncertainty may arise from a system’s

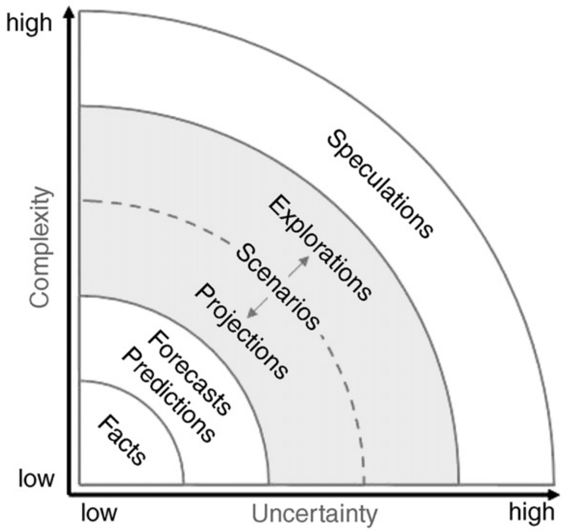

Fig. 1. Scenarios can help address uncertainty in complex systems — note that scenarios differ from facts, forecasts, predictions and speculations (figure inspired by [27] and other sources).

complexity itself, or may be related to determining future developments. In cases of a relatively low uncertainty with regard to determining developments, scenarios allow projecting future implications (often these then involve reference scenarios, sometimes with alternative projections around these). Alternatively, if large questions exist how driving forces may play out (especially in the longer-term future), scenarios help exploring the implications of a range of different futures (commonly this results in sets of contrasting scenarios that outline a realm of plausible futures). Often this makes it necessary to reduce the complexity of systems before analysing them, either by looking only at parts of a system or by focussing on a very concrete focal question in the scenario process.

To address the way a complex system may develop, scenarios bring together different elements and combine them to develop images of the future. These elements usually include a number of focal questions (i.e. regarding the main uncertainties) a scenario is built around, a set of driving forces that shape the system's developments, the basic overarching logic and decision-making paradigm portrayed in each scenario, as well as an elaboration of future outcomes that may be of interest to the scenario users.

Scenarios should not be confused with forecasts or projections. In contrast to these approaches, scenarios do not necessarily assume that the world will remain within today's boundary conditions in the future. Indeed, scenarios (especially when geared to be exploratory) are often explicitly based on the assumption that future boundary conditions may be subject to substantial change. Thus they allow thinking through the implications of decisions and actions taken today within altered future conditions, and are useful for thinking about dynamic processes and causal chains that affect the future, e.g. [19].

Indeed, scenarios can serve a range of different purposes. These can be grouped roughly in three general categories: Science and research, education and information, strategic planning and decision-support. Within science and research, for example, scenarios can help explore the understanding and dynamics of a system by exploring the interactions and linkages between key variables or driving forces as the scenario plays out. In the wider context of education and information, scenarios can provide a useful tool for ordering, conveying and/or illustrating different perceptions about alternative future environments. Finally, scenarios may highlight upcoming choices to be made and their long-term consequences. With the latter, scenarios also serve to support strategic planning and decision-making by providing a platform to think through the implications of alternative options in the face of uncertain future developments, which also allows for voicing conflicting opinions and world views.

Within international environmental assessments an important function of scenarios is that they can act as bridge between science and policy. Indeed, scenario development and analysis provides an approach to reflect on and think through the possible implications of different decision paths in a structured manner, while embracing uncertainty about future developments. In other words, this allows specific *decision units* (be it an individual, a company, an organisation or even a country) to think about implications of changes in a wider *decision context.* This context is usually outside the immediate sphere of influence of the decision unit itself, yet sets the boundary conditions against which any decision needs to be taken. Nevertheless, in some cases feedbacks between the decision unit's behaviour and the contextual developments exist.

For the sake of illustration, consider the issue of how a (small) country may respond to the threat of future climate change. Climate change is driven largely by greenhouse gas emissions at the global scale, to which this small country contributes to a rather limited extent. Here, global climate change provides a *decision context*, to which the country as a *decision unit* may want to respond by devising, say, a national climate change strategy. While such strategy might largely be limited to anticipating and responding to the context of global climate change, it may also to some degree feedback on how future climate change unfolds, e.g. within a global discussion of climate change.

Scenarios that are developed in support of strategic planning and decision support – i.e. to support individual decision units respond to plausible future contexts – need to clearly distinguish the roles of decision unit and decision context. As a consequence, the manner in which uncertainties are addressed needs to relate to the purpose of the scenarios. Furthermore, it has been argued that the purpose of scenarios, and their development process, varies with the geographical scale they address, e.g. [9].

At a global- or macro-scale scenarios are often developed with the aim to explore and illustrate plausible futures and how socio-ecologic systems function, also in the view of informing wider policy discussions, the general public as well as specific user groups. In this general context, scenarios may benefit from addressing uncertainties of the decision context and responses by the decision unit in a combined manner. Indeed, often a key objective of such scenarios is to identify feedbacks between the two, and to highlight the respective dependencies.

Conversely, when addressing issues on a more local- or micro-level relevant to a particular decision unit, scenario development should commonly aim to support on-going decision processes (in an interactive and/or participatory manner). Here it is essential to allow for, or arrive at, a clear distinction between the uncertainty in the decision context and the ability of the respective decision units to act in response to possible future developments.

Different purposes call for different degrees of compatibility and thus for different approaches to linking scenarios across scale.

3. Approaches to linking scenarios across geographical scales

Scenarios developed in international environmental assessments usually provide a wealth of information about plausible future developments at global scale; yet also give some indication of regional developments, see, for example, [1–3]. Indeed, some existing regional or local environmental scenarios have linkages with global scenarios — and in some cases have even been derived directly from these. Here we explore when linking scenarios across geographical scales might be useful and give an overview of approaches to do so. While we focus on linking scenarios across geographical scales, other ways of combining scenarios, such as 'nesting' scenarios of varying degrees of detail developed to address similar topics or issues, have been discussed elsewhere [20].

There are a number of reasons that make linking scenarios across different geographical scales desirable. Linking scenarios is generally useful when the processes at different scales directly depend on each other. Climate change as a global phenomenon for example, is likely to affect biophysical processes across the world in the same way, while regional socio-economic developments govern future climate trajectories to a large extent. In addition, for many environmental issues, the global context is as important as regional developments. This makes it imperative to place regional scenario exercises within a global context. On the other hand, it is often important for a regional or local decision unit to differentiate between developments (s)he can or will influence through a certain decision or behaviour and the ones that (s)he will have to adapt to. Understanding which global factors or driving forces are external to the local or regional system will be of importance for setting boundary conditions for developing timely response options (e.g. mitigation versus adaptation strategies to global environmental changes).

Furthermore, a wealth of information is available in existing scenarios, and making use of the existing knowledge helps focus attention and effort to discuss those aspects that are especially relevant at a lower geographical level. Finally, linking scenarios across different geographical scales can also help in bringing

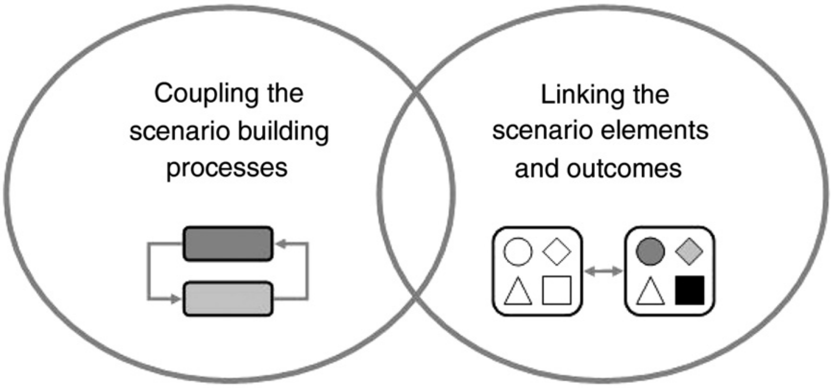

Fig. 2. Two different concepts of linking scenarios across geographical scales.

together stakeholders, researchers and decision-makers from different geographical settings, and thus helps create a greater and shared knowledge about issues in environmental assessments.

Scenarios can be linked across geographical scales in two ways; via the scenario development *processes* or via the scenario *elements*, see Fig. 2:

First, the scenarios themselves, that is to say their *elements* or *outcomes*, can be linked across different geographical scales. The linkages vary by the degree of interconnectedness and here we distinguish five principal types: *Equivalent*, *Consistent*, *Coherent*, *Comparable*, and *Complementary* Scenarios. Second, the *processes* by which the scenarios are developed can be coupled in various ways. Again, we distinguish five different possibilities for doing so: *Joint*, *Parallel*, *Iterative*, *Consecutive*, and *Independent* scenario development processes.

Depending on the type of coupling in scenario development processes as well as the degree of aspired linkages of actual scenario elements, the 'strength' of the cross-scale link will differ: ranging from fully equivalent scenarios developed in joint processes at two or more geographical scales, to complementary scenarios developed in independent processes that share not much beyond a general theme.

3.1. Linkage between scenario elements or outcomes across geographical scales

Scenarios developed at different geographical scales can be linked by using the same scenario elements, such as the same driving forces, same assumptions, same scenarios logics, same boundary

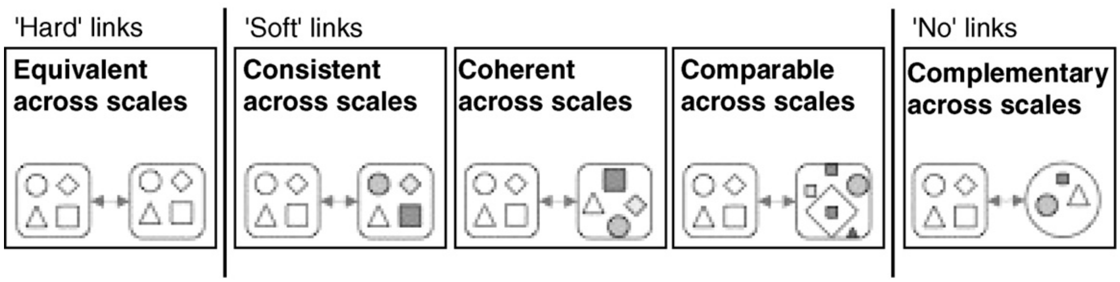

Fig. 3. Degrees of linkages of scenario elements and/or outcomes.

conditions, same governing decision-making paradigms or even same general outcomes. The degree of how similar scenarios are to each other across different scales can vary and of course also largely depends by which process the scenarios were developed (see Section 3.3). We distinguish between five different ways of linking scenario elements and/or outcomes across scales (Fig. 3).

3.1.1. Equivalent[1] across scales // downscaling the scenarios (statistical, dynamic)

To achieve congruency in scenarios across scales, the general logic and assumptions as well as the outcomes of the scenarios at one scale are transferred to the other scale. In most cases this works best by going from higher to lower scales. Quantitative scenarios are down-scaled either in a purely statistical manner or by using dynamic scaling methods. Within qualitative scenarios, developments that unfold at one scale are assumed to play out following the same trend as in the other scale. In many ways the scenarios at the lower scale can be seen as a 'true' subset of the higher scale. The advantage of scenarios being equivalent across scales is that they are fully consistent and can be used interchangeably at the different scales. This also allows demonstrating how a specific development at the global level might play out similarly in different regions of the world. This method is thus particularly useful when scenarios focus on illustrating the impacts of global developments at a lower geographical scale, for example with the purpose of information dissemination. A key disadvantage of this approach is that the main questions the scenarios address at the global scale may not be relevant or interesting at the regional or local scale. Thus the 'purely' down-scaled scenarios are prone to loosing relevance at lower scales for informing decision-making processes. An example of down-scaled scenarios are many climate change scenarios, in which the emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) [1] at a global scale are used to derive emission levels in specific regions and to develop from that scenarios about temperature changes or climate variability in these areas.

3.1.2. Consistent[2] across scales // fixing the boundary conditions (assumptions, drivers)

The main scenario assumptions and the selection of driving forces and their trends are set to be consistent with each other in both scenario exercises. Basically, the higher scale scenarios provide strict boundary conditions for lower scale scenarios. The scenarios thus also play out in similar ways at the different scales, their main assumptions on drivers and scenario logics are fully consistent. Some of the concrete outcomes at the various scales may differ, as long as these deviations do not challenge the governing scenario logics and assumptions made. An advantage of building consistent scenarios across scales is that one can, for example, explore similar trends across regions and compare their outcomes with each other. If outcomes differ from one area to another, one can look for differences in conditions in each region (economic, environmental, institutional, etc.) at the beginning of each scenario which sheds light on the importance of specific factors for the development of the area. Consistent scenarios share the problem of loosing relevance to decision-makers at the lower scale with equivalent scenarios, where the limitations in varying across scales are even stronger. Thus they are usually more useful for academic analysis and for information purposes.

[1] Definition: *Equivalent* — capable of being placed in one-to-one correspondence (Merriam Webster Online Dictionary, www.m-w.org).

[2] Definition: *Consistent* — marked by harmony, regularity, or steady continuity; free from variation or contradiction (Merriam Webster Online Dictionary, www.m-w.org).

3.1.3. *Coherent[3] across scales // transferring the scenario logics*

Coherent scenarios follow the same paradigm or are different representation of the same scenario archetype — in other words the scenario logics 'match'. Thus this kind of scenarios explores what happens at different scales if decision-makers at the different levels use a similar logic/way of thinking or have similar assumptions about the future. This does not preclude substantial differences with regard to how the scenarios play out, both in the selection of important driving forces, their major trends and/or scenario outcomes. If, for example, one of the main assumptions about the future is that globalization will continue over the next 20 years in a similar mode as today, a national policy maker might want to think about the implications of this trend for the national industry and national markets. A local decision-maker that has the same assumption might think about adjusting to new competitors on the local and national market. The outcome within a scenario might be quite different; yet the underlying ideas about the future would be the same. Coherent scenarios have the advantage of helping to unearth the underlying assumptions within a range of different decision-making processes. This also furthers the understanding on where differences in opinions about possible policy choices and their implications for the future come from. Thus, these kinds of scenarios are commonly geared towards directly informing decision-making and planning processes. Nevertheless, it might be difficult to find scenario archetypes that apply to all scales or cover the main assumptions and ideas at each scale. Examples of coherent scenarios include the pilot scenarios developed by the Global Environmental Change and Food Systems (GECAFS) Caribbean scenarios exercise [21] which use the MA global scenarios [18] as their starting point.

3.1.4. *Comparable[4] across scales // addressing the same focal issue*

Comparable scenarios may be constructed to be largely independent at different scales, connected mainly by the issue they address. For example, they might address the same focal issue or use a comparable analytical framework, but arrive at very different, even contradicting sets of scenarios at different geographical scales — the link between the scenarios is very loose. Comparable scenarios have the benefit that they give the scenario developers a lot of freedom to focus on the specific policy, planning or management questions pertinent to their area and their geographical scale, while still maintaining a general link to other scenario exercises through the shared concepts or general issues to be addressed. Thus the exercise gains in relevance for stakeholders, but for that the comparability across scales regarding outcomes, similar trends, etc. becomes more difficult. Examples of comparable scenarios include the ones built by the MA [18]. Some of the sub-global scenarios built in this exercise, were based on the general concepts of ecosystem services, drivers, main focal issues etc. as the global MA scenarios, but they did not strictly cohere with the scenario logics or the main trends addressed at the global scale. Another example of comparable scenarios are those developed in the World Water Vision [22]: the scenarios developed in this international assessment included both a set of global scenarios and a variety of substantially different scenarios developed in independent regional scenario exercises — all of which nevertheless addressed the issue of water scarcity from a similar angle.

[3] Definition: *Coherent* — logically or aesthetically ordered or integrated (Merriam Webster Online Dictionary, www.m-w.org).

[4] Definition: *Comparable* — capable of or suitable for comparison, also: similar (i.e. not differing in shape but only in size or position) (Merriam Webster Online Dictionary, www.m-w.org).

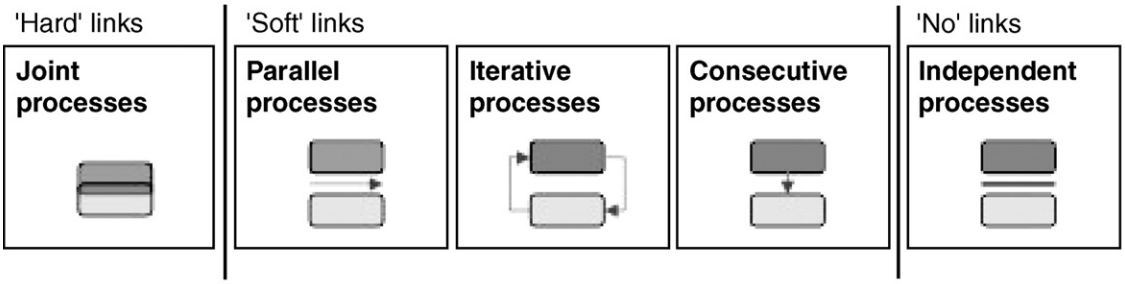

Fig. 4. Approaches to couple scenario development processes at different geographical scale.

3.1.5. Complementary[5] across scales // 'borrowing' from similar scenarios

The logics and assumptions in complementary scenarios differ across scales, but this does not preclude selected information from scenarios at one scale to feed into scenarios at another. The scenarios can differ substantially at the various spatial scales, and even contradict each other — nevertheless by this they also complement each other as they illustrate how an issue may be perceived differently at different scales, or even how issues differ in their relevance. Indeed, most scenarios developed in independent processes can be regarded as complementary, even if they address similar issues. (See, for example, the three different European land use scenarios recently developed and analysed in three independent projects: Advanced Terrestrial Environmental Assessment Modelling (ATEAM) [23], EURuralis [24], and the Prospective Environmental Analysis of Land Use Developments in Europe (PRELUDE) [25].)

3.2. Coupling the scenario development processes at different geographical scales

Irrespective of how closely the scenarios themselves are linked at different geographical scales, the scenario development *processes* can be coupled across different regions and geographical scales. We here distinguish five approaches (Fig. 4):

3.2.1. Joint scenario development process

Scenarios can be developed at different geographical scales in a joint scenario exercise, with the same group of scenario developers detailing scenarios at each geographical scale within a single assessment. In some recent examples the same modelling framework has been applied to quantify plausible developments across different scales. This will usually lead to a high level of consistency between scenario elements at different geographical scales. At the same time, regional specific developments commonly will not be addressed with the same detail as those that occur at the global scale. An example for such an approach is the quantification of the GEO-3 scenarios; see [2] and [26].

3.2.2. Parallel scenario development process

Here different groups of scenario developers build scenarios at different scales, in more or less parallel processes. 'Parallel' may here refer to (i) addressing the same focal question and conceptual frameworks (e.g. World Water Vision), (ii) applying the same general approach to scenario development (e.g.

[5] Definition: *Complementary* — mutually supplying each other's lack (Merriam Webster Online Dictionary, www.m-w.org).

Millennium Ecosystem Assessment), (iii) using the same sources for information and quantification, (iv) or even being physically in the same location. The advantage of this approach is that each parallel process can focus more specifically on issues relevant to policymakers at each level. Using a common conceptual framework then helps to address the same issues in a similar, consistent way by using the same concepts, analytical tools or output variables. Maintaining consistency and/or coherency across the scenarios developed at the different scales though can be difficult and requires special attention to the linking process.

3.2.3. Iterative scenario development process

In this type of process, scenario development is initiated at one scale and a set of draft scenarios is developed. These drafts then provide the starting point for scenario development at another scale. Once the second scenario process is finalized, the first set of draft scenarios are revised and finalized based on the input from the other scale. In this way, a large degree of consistency or coherency between the different geographical levels can be ensured. The on-going GECAFS project gives an example for such a process (although here the Millennium Ecosystem Assessment scenarios provide the draft global GECAFS scenarios — which will be revised based on the input of different lower scale scenario exercises to form a final set of GECAFS global scenarios) [21]. The iterative approach allows for explicitly addressing and tracking cross-scale processes. Participants in the process should therefore include representatives of the different scales addressed by the exercise. Their interaction will further enhance the 'learning across scales' process. Nevertheless, over the course of the exercise it is possible that disagreements arise on how the cross-scale processes work and what their impact on a specific scale might be due to participants' perspectives that can vary with scale. This can potentially jeopardize the scenarios exercise, while it is also an important learning opportunity for scientists and policy makers alike. In addition, the iterative approach is also quite time consuming and requires a number of meetings to finalize the exercise.

3.2.4. Consecutive scenario development process

Scenarios are first developed and finalized at one geographical level. Based on these, scenarios are developed and fleshed out at another geographical level — while the original scenarios stay unaltered. Many, or even most of the IPCC scenario derivatives are developed following a consecutive process — the original IPCC scenarios thus far provide an unaltered global set, on the basis of which regional scenarios are detailed. Consecutive scenario development has the advantage that the 'follow-up' process begins from a clear starting point and that the derivative scenarios can therefore be developed with a lot of consistency among them, if desired. Nevertheless, as there is no planned iteration or interaction between different scales or among derivative scenario exercises it is more difficult to learn about how cross-scale processes work or compare their impacts across regions.

3.2.5. Independent scenario development process

Scenario development processes at two or more geographical scales can be fully independent from each other. In this case though, respective scenarios may still provide input and information to each other, but in an informal manner only. In addition, one can map independently developed scenarios later on onto each other to analyse their differences and similarities. This analysis can provide new insights for example into the opinions about and aspiration for the future articulated by different scenario building groups and their stakeholders. Scenarios developed in independent processes have the advantage that they can address precisely the needs and questions of the decision-makers/stakeholders at the scale that they are developed, which results in highly relevant scenario for the end-users. Most scenario exercises up to date belong to this category. By not taking scale issues into account within the actual scenario development process (although they can be an implicit part of the contents of the scenarios), it is more likely that some cross-scale interactions will be overlooked or only marginally addressed.

3.3. Relationship between the degrees of linkage between scenario elements or outcomes and the coupling of scenario development processes across geographical scales

While there is no straightforward mechanism by which a certain scenario process leads to a certain degree of linkage in the scenarios and their elements across scale, some correlation between coupled processes and linked outcome exists — see Table 1.

Scenarios developed by a single group of people for different scales simultaneously (i.e. in a 'joint process') are very likely to be almost equivalent or consistent. However, the scenario developers may from the outset aim for dedicated scenarios to address different issues of particular relevance to the different scales (and possibly in an inconsistent manner). It is unlikely though, that a group of scenario developers uses entirely different approaches at different scales, rendering scenarios that are complementary only to be rather unlikely in a joint process.

In a 'parallel process' different groups of people develop scenarios, and the degree to which these follow common frameworks depends on how intensively the respective groups coordinate their scenario development. Without any coordination, complementary scenarios are likely. However, by the nature of parallel process some coordination or at least a common conceptual approach to the focal issues of the scenarios is likely to lead to comparable or even coherent results. Also consistent scenario outcomes are

Table 1
Relationship between scenario development processes and scenario outcomes across geographical scales — while any process can lead to any degree of linkage, some are more likely than others

	Joint process	Parallel process	Iterative process	Consecutive process	Independent process
Equivalent across scales	**Very likely**, if a denominator for S1 + S2 exists	**Unlikely**, requires rigorous S1 + S2 coordination	**Possible**, with unifying S1 + S2 sessions or models	**Likely**, if S1 defines reference input/data for S2	**Very unlikely**, no coordination between S1 and S2
Consistent across scales	**Possible**, but only if it is explicit aim of S1 and S2 by same group	**Possible**, but only if both S1 and S2 explicit aim for	**Very likely**, if S1 or S2 incorporate respective inputs	**Very likely**, if S1 sets binding boundaries for S2	**Unlikely**, only S1 and S2 if are *de facto* consecutive
Coherent across scales	**Possible**, if S1 and S2 emphasise different issues	**Likely**, if S1 and S2 share starting point, and deviate	**Likely**, if S1 and S2 follow same paradigm only	**Very likely**, if S1 provides starting point for S2	**Unlikely**, only if S1 and S2 are *de facto* consecutive
Comparable across scales	**Possible**, if S1 and S2 are developed in parallel *de facto*	**Very likely**, S1 and S2 adopt the same conceptual frame	**Possible**, if S1 and S2 aim to address different needs	**Likely**, deviation if different focus S1 and S2, same frame	**Possible**, if S1 and S2 use similar conceptual frame
Complementary across scales	**Unlikely**, as S1 and S2 conceptually independent here	**Likely**, if S1 and S2 are parallel yet autonomous	**Unlikely**, this implies that iteration fails	**Possible**, if S1 provides info only for S2	**Very likely**, S1 and S2 address similar issues differently

[Note: S1 and S2 denote two separate scenario exercises at two different geographical scales.]

possible, but usually require either active coordination or even iteration between groups. One approach towards coherency or consistency in scenarios developed in parallel process is to have part of the scenario developers group participate at both scales (i.e. leaving a hybrid 'joint-parallel' process).

Similarly, the degree of consistency of scenarios developed in 'iterative process' much depends on the willingness of different groups to incorporate input from scenario development at another scale and/or from a coordination team. In this process, the question of consistency is one of choice and guidance. Groups may decide that their respective counterparts at another scale are not developing scenarios that are useful for the discussions at their scale (resulting in comparable scenarios), or, conversely, that consistency takes precedence over any other concern (leading to fully consistent scenarios). Even equivalent scenarios are possible in this approach, but usually require that some common modelling framework is applied.

Also a 'consecutive process' may lead to consistency in the scenarios developed, depending on how binding the scenarios developed at the primary scale are treated in the subsequent development at another scale. Here the linkage of outcomes is merely a question of choice, ranging from full equivalence and consistency to largely inconsistent and complementary scenarios. This will depend much, on whether the results are easily transferable from one scale to another, and whether the primary scale already addresses issues as relevant for the secondary scale.

Finally, 'independent processes' by their very definition do not *per sé* lead to any consistency in the linkages (although comparable or even consistent scenario may evolve due to a similar understanding of issues by independent groups). The most likely outcomes with this process are complementary scenarios at different scales, each tailor-made to address issues most relevant to the respective scales.

4. Discussion and conclusions

Advancing our understanding of how social and ecological processes interact and influence each other across time and geographical scales requires developing new and advancing known analytical tools. Scenario analysis provides a good basis to analyse plausible future developments as this method aims at looking into the future in a structured manner and can address processes that work across geographical scales, if desired. There are various ways of systematically linking scenarios across geographical scales that we have described in this paper, which offer the possibility to better study cross-scale linkages. These links can be achieved either within a scenario development process, or in the scenarios developed and their elements.

This leaves the question which approach, i.e. which process and how much linkages, are needed to develop a good set of scenarios across scale. The answer is somewhat unsatisfying: 'It depends on the purpose of the scenario exercise'. When scenarios are developed for use in the research realm a high degree of consistency, preferably even equivalence, is desirable, as this allows analysis of the dynamics at different scales together. Examples for this are the IPCC-based scenarios for climate change, where consistency between elements at global level and regional level is paramount to understand fully the implications of emissions globally for regional development. Here the complex decision context for regional players depends largely on global trends. The IPCC process is a prominent example for an (originally) joint process during their development, and how these scenarios provide a starting point for many 'consecutive' scenarios processes. An important reason for this is that using the global information to set boundary conditions for lower scale scenarios can prevent much work that otherwise would have to be redone for a regional exercise, while maintaining a scientific credible global context.

However, for supporting discussion in a regional or local decision unit, the issue of cross-scale consistency may be less important. Information from global scenarios may provide a useful backdrop for regional scale scenario development, but may not capture or even mis-represent important regional dynamics. Here, it depends to what degree the decision context is shaped by global scale processes versus regional scale developments. Particularly the dynamics within a socio-economic system is often driven primarily by regional scale developments (though the 'rules of the game' are currently changing with many globalization processes). In this case, higher scale scenarios may provide a useful starting point, but eventually it may be more important to maintain regional relevance (by for example having an 'independent', 'consecutive' or 'parallel' process at regional scale). The importance of these scenarios really lies in their relevance for decision-makers 'on the ground'.

From this discussion it can be seen that scenarios provide a very useful tool to address cross-scale feedbacks and facilitate multi-scale discussions. We have identified various ways in which a scenarios exercise can be set up for this purpose and either the development process or the scenario elements be linked. Nevertheless, scenarios exercises are not the only possibility to investigate linkages between different geographical scales while thinking about their future impacts. They definitely have a number of advantages, such as their flexibility and creativity and the possibility to include stakeholder in various ways in the discussion, but they are also not easy to set up and require skilled process facilitation to obtain useful results. In addition, they can also be rather time and resource consuming. And in some cases, very much contradictory to their actual purpose, scenarios can actually contribute to a false sense of certainty about the future, which is why their careful use and dissemination is quite important. And with respect to addressing cross-scale interactions, scenario exercises do not necessarily produce new knowledge, but they definitely help to clarify and re-assess what we know and what we don't know about these processes.

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